Benthic Studies in Alice Arm, B.C., Following Cessation of Mine Tailings Disposal

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ABSTRACT

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm, B.C., following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 37, 1-57.

Benthic invertebrates were collected and identified from Alice Arm and Hastings Arm, British Columbia, in October 1983 to determine the effect of mine tailings on the benthic community approximately one year after discharge from the Amax/Kitsault mine ceased. Current benthic invertebrate data were compared with data from a study conducted prior to mine closure. Taxonomic analyses indicated that the total number of benthic invertebrates from a group of three stations showing maximum impact of mine tailings in 1982 increased fourfold, while invertebrates obtained from transects further down inlet in Alice Arm and Hastings Arm decreased two- to threefold compared to 1982. Hierarchical analyses indicated that sampling stations along the two transects nearest the discharge (Transects CC and DD) could no longer be clearly differentiated into the pattern observed in the 1982 data. The sites further down inlet (Transect D.5) showed only intermediate or fringe effects in 1983, and the area sampled nearest the mouth of Alice Arm (Transect EE) showed no apparent effects. Transects near the mouths of both Alice and Hastings Arms served as stable reference areas.

Key words: benthic invertebrates, mine tailings, fjords.

RESUMÉ

Kathman, R.D., R.O. Brinkhurst, R.E. Woods and S.F. Cross. 1984. Benthic studies in Alice Arm, B.C., following cessation of mine tailings disposal. Can. Tech. Rep. Hydrogr. Ocean Sci. 37, 1-57.

En octobre 1983, on a recuilli des invertébrés benthiques dans les bras Alice et Hastings (Colombie-Britannique) et on les a identifiés afin de déterminer l'incidence des stériles miniers sur la communauté benthique environ un an après que les déversements de la mine Amax/Kitsault eurent cessé. On a comparé les données actuelles sur les invertébrés benthiques avec celles générées par une étude menée avant la fermeture de la mine. Selon des analyses taxonomiques, le nombre total d'invertébrés benthiques obtenus à trois stations regroupées indiquant les effets les plus importants causés par les stériles en 1982 avait quadruplé, tandis que l'abondance des invertébrés échantillonnés dans des transects plus en aval dans les bras Alice et Hastings avait baissé de deux à trois fois en 1983. Des analyses hiérarchiques portent à croire que les stations d'échantillonnage le long des deux transects les plus près du point de deversement (transects CC et DD) ne pouvaient plus être différenciées clairement selon le schème observé en 1982. Les sites plus en aval (transect D.5) ne révélaient que des effets moyens ou faibles en 1983 et la région la plus

près de l'embouchure du bras Alice (transect EE) ne montrait aucun effet apparent. Les transects près des embouchures des bras Alice et Hastings ont servi de bonnes zones témoins.

Mots-clés: invertébrés benthiques, stériles miniers, fjords.

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SUMMARY

Benthic invertebrate samples were collected in Alice Arm and Hastings Arm, British Columbia during October 1983. Composition, distribution and abundance of the benthos were analyzed to determine the effects of mine tailings on infaunal benthic communities one year after discharge ceased.

In 1982 Sites CCN, CCM and DDM, contained very few species and individuals, and clustered as a distinct grouping, indicating that these areas were severely stressed from the nearby tailings discharge. In 1983, however, all the sites on Transects CC and DD clustered together. Sites CCN, CCM and DDM could no longer be clearly differentiated, indicating that benthic invertebrates had been recolonizing the stressed areas.

The areas in Alice Arm most adversely affected by tailings deposition in 1982 (Sites CCN, CCM, DDM) had a 256% increase in number of taxa and a 367% increase in number of individuals during 1983. Most other sites in Alice and Hastings Arms had substantial decreases in both numbers of taxa and individuals for 1983. However, both density and diversity increased as distance from the former discharge increased.

Infaunal composition progressively changed from a dominance of polychaetes near the former discharge to a dominance of molluscs near the mouth of Alice Arm and in Hastings Arm. Polychaetes thus appear to be the primary colonizers in Alice Arm following cessation of mine tailings discharge.

INTRODUCTION

A study of the effects of mine tailings deposition on subtidal benthic invertebrates in Alice Arm was undertaken in October 1982 after 18 months of mine operation and tailings discharge (Kathman et al., 1983). The areas nearest the outfall had very few species and individuals, while the sites further down inlet had greater individual abundance and diversity. Reduced numbers of species and individuals were noted in the deep middle sites in the inlet approximately 8 km down inlet from the discharge, suggesting that mine tailings were beginning to affect the benthos in the seaward deeper section of Alice Arm. In November 1982 the Amax/Kitsault mine closed indefinitely and all tailings discharge ceased. The same sites were then resampled in October 1983, 11 months after closure to determine what further changes had taken place in the infaunal benthic community.

The mine closure afforded an excellent opportunity to determine:

a) the effects of mine tailings on the marine benthic community after cessation of tailings discharge,

b) the identity and numbers of initial colonizers of the tailings, and

c) infaunal benthic recolonization of the tailings.

TERMS OF REFERENCE

The overall objective of this study was to determine the composition, abundance and distribution of the benthic invertebrate fauna in Alice Arm and compare these results with findings from 1982. Specific tasks were to:

1. Collect infaunal benthic invertebrates from four transects in Alice Arm and one transect in Hastings Arm.

2. Sort and identify the benthic invertebrates retained by a 1.0 mm mesh screen.

3. Perform hierarchical (cluster) analysis on the taxonomic data, ensuring comparable analytical techniques for 1982 and 1983.

4. Prepare a reference collection of the benthic species identified, to be deposited with Ocean Ecology Division, Institute of Ocean Sciences.

5. Prepare a technical report incorporating the above information to determine whether changes have occurred in the Alice Arm benthic community.

METHODS

Sampling

Sampling in Alice Arm and Hastings Arm, British Columbia (Fig. 1), was conducted by personnel from the Institute of Ocean Sciences and E.V.S. Consultants aboard the C.S.S. Vector in October 1983. Sampling procedures were essentially the same as those used in 1982 (Kathman et al., 1983). Duplicate samples were taken at each station on predetermined transect lines (Fig. 2) using a 0.1 m^2 Smith-McIntyre grab. Transect D.5, located between Transects DD and EE, was added to more clearly delineate the extent of tailings effects. A single transect in Hastings Arm (Z2) was retained as a reference location for comparison with the sites in Alice Arm. Each sample was washed through a 1.0 mm screen. The contents retained on the screen were placed in labelled plastic bags and preserved with seven percent formalin with phloxine-B, a histological stain used to facilitate sorting. Pertinent information recorded during the sampling is presented in Appendix A.

Sorting and Quality Control

Upon receipt of the samples by the E.V.S. Consultants Taxonomy Centre, each sample was washed through a 1.0 mm sieve to remove excess formalin. Aliquots of each sample were examined using a Wild M5A stereomicroscope until the entire sample was sorted and all organisms removed. Organisms were counted, placed into separate containers filled with alcohol and labelled according to the following major taxonomic groups: Amphipoda, Cumacea, Other Crustacea, Polychaeta, Gastropoda, Bivalvia, Scaphopoda, Coelenterata, Echinodermata and Others. Sample residues were returned to their original sample bags and re-preserved with seven percent formalin.

To ensure accurate sorting, 25 percent (seven of 30) of the sample residues were independently resorted by the taxonomic supervisor following the procedure outlined above. If additional organisms were found, they were placed in the appropriate vial and all necessary changes made to the data sheets. Quality control data are provided in Appendix B. Percent error ranged from 0 to 1.6, well within the requisite limits for accuracy of sorting of benthic invertebrate samples.

Identification

Recognized taxonomic experts identified all organisms to the lowest possible taxonomic level consistent with the presently-available literature. A list of the taxonomic references used for identifications is provided in Appendix C, and a listing of all benthic invertebrates collected during this study is provided in Appendix D. Distributional data are provided in Appendix E for Alice Arm and Appendix F for Hastings Arm.

A representative specimen (or specimens) of each genus/species was removed from the collection and presented to the Scientific Authority as a reference set for future use. The bulk of the specimens from the 1982 and 1983 studies was deposited with the B.C. Provincial Museum (Victoria).

Fig. 1. Map showing general location of study area.

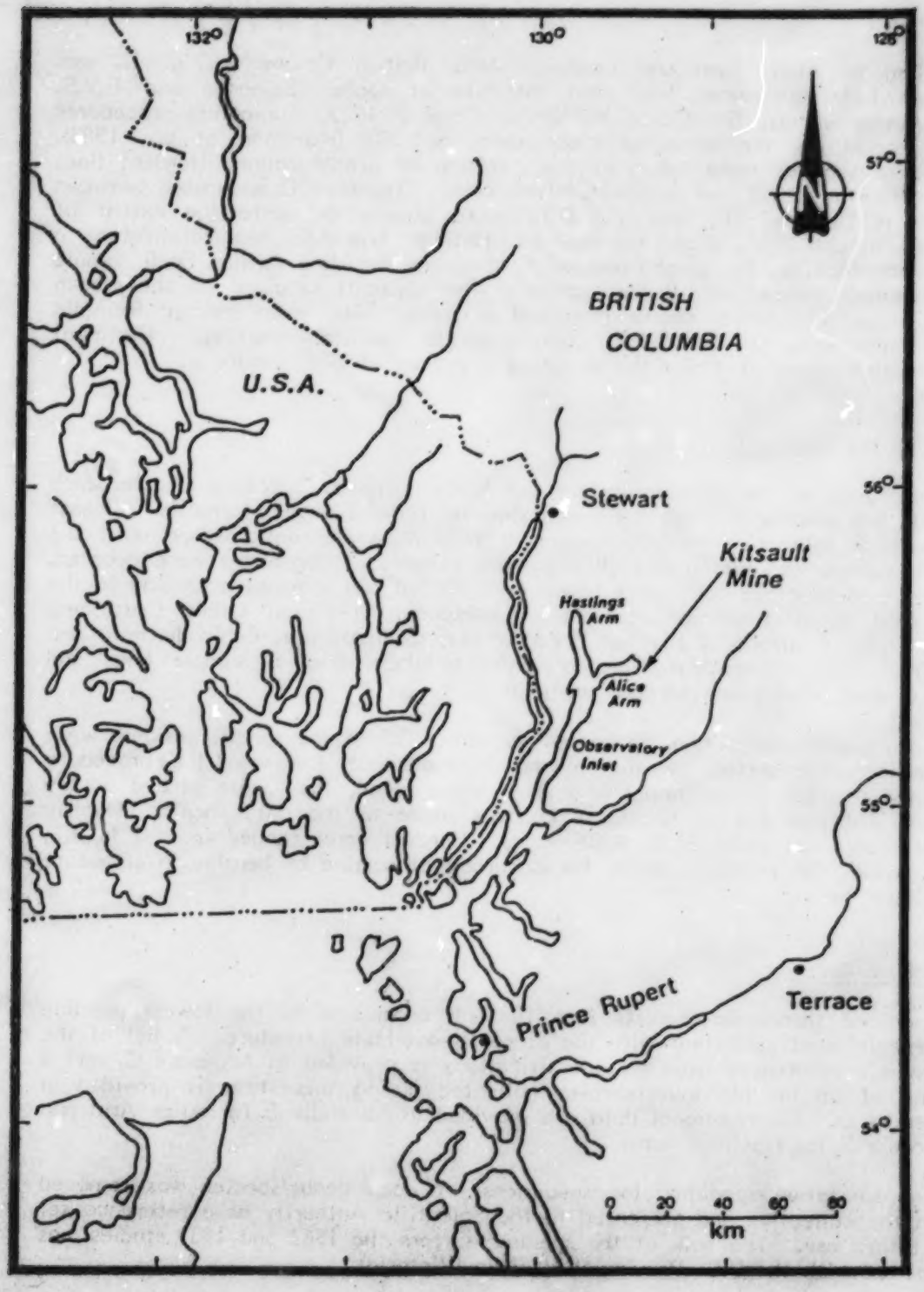
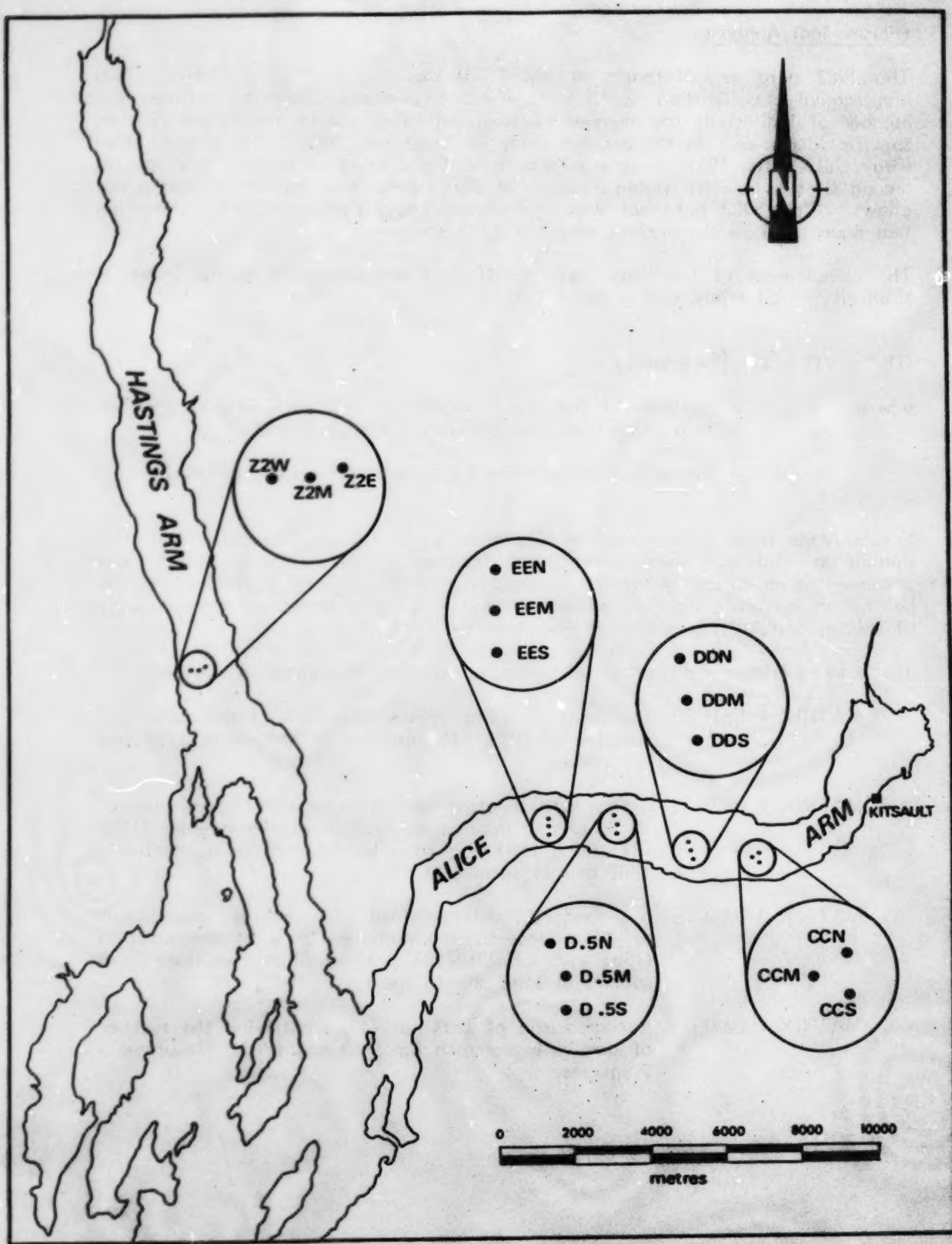


Fig. 2. Station locations in Alice Arm and Hastings Arm, British Columbia.



Hierarchical Analysis

The 1982 data set (Kathman et al., 1983) was analyzed using Ward's (1963) hierarchical classification coefficient, which emphasizes similarity between the number of individuals and number of taxa, but does not utilize information on specific identities. In the present study we used the Bray-Curtis classification (Bray and Curtis, 1957) to take into account the affinity or similarity of species among sites as a more viable measure of discreteness than the Ward coefficient allows. The 1982 data set was re-analyzed using the Bray-Curtis clustering technique to allow comparison with the 1983 data.

The complement of the Bray-Curtis coefficient was employed as the index of similarity in all trials, and is defined as

(1) $C = 1 - [2w \div (a+b)]$

where w = the sum of the lesser abundances for each species common to a pair of samples (in Q-type analysis), and

$(a+b)$ = the sum of abundances for each sample under comparison.

Values range from 0 for complete dissimilarity, to 1.0 for complete similarity. Pair-group clustering was unweighted (arithmetic means) and output was displayed as an optimally rotated dendrogram. Analyses were performed on the benthic invertebrate data to allow comparison of sites, based on the similarity of species composition and mean abundances (Q-type).

The data matrices employed in all subsequent 1982/1983 comparisons were

MATRIX 1 (M1) : the original data minus Site Z5, which was not sampled in 1983. Resultant - 79 species in 1982 and 67 species in 1983;

MATRIX 2 (M2) : a first edit deleting taxa with recorded abundances of 10 or less in approximately 95% of the samples (1982 -22 of 23; 1983 - 29 of 30). Resultant - 31 species in 1982 and 21 species in 1983;

MATRIX 3 (M3) : a second edit deleting taxa with recorded abundances of 20 or less in approximately 95% of the samples (1982 - 22 of 23; 1983 - 29 of 30). Resultant - 24 species in 1982 and 15 species in 1983;

MATRIX 4 (M4) : a comparison of lists for M3, identifying the number of species in common for 1982 and 1983. Resultant - 9 species.

RESULTS

Hierarchical Analysis

This report focuses on the M1 original data matrices to allow full comparison between the years. However, the results of cluster analysis by site for all four data matrices (M1-M4) showed the same patterns in 1982 and 1983, respectively, (App. G and H), indicating that rare taxa present at low abundances do not contribute significantly to the overall pattern or interpretation of the data.

Comparisons between the Ward and Bray-Curtis cluster groupings for the 1982 15-station data sets showed both similar and divergent patterns among clusters (Figs. 3 and 4). Sites CCN, DDM and CCM comprised a distinct cluster group in both analyses, reinforcing the large differences that existed between the benthic invertebrates at these sites and the remaining sites. Although these three sites separated into distinct clusters using both analyses, the apparent high degree of similarity within the cluster using Ward and low degree of similarity using Bray-Curtis was due to the former considering only diversity and abundance, whereas the latter also incorporated similarity among the species into the analysis. Site DDS was an outlier by Bray-Curtis, while CCS was more closely aligned with DDN, EEM and the Hastings Arm stations (Fig. 4). Sites EEN and EES showed a high degree of similarity in both analyses, but combined were dissimilar to EEM using the Bray-Curtis technique (Fig. 4) compared to being very similar using Ward's technique (Fig. 3).

Because the Hastings Arm Z5 stations were not sampled in 1983, cluster analysis was performed using the 12 sampling site M1 data matrix for 1982 (omitting the three Z5 stations) for comparison with the full 1982 data set (Figs. 4 and 5). Elimination of the three Z5 sites in the analysis resulted in only minor changes in the general pattern. All further 1982/1983 comparisons are made with Fig. 5, the baseline cluster grouping.

The 1983 M1 cluster groupings are shown in Fig. 6 and are compared to Fig. 5. The two obvious differences in 1983 are

(1) the three stations comprising each of the Transects D.5, EE and Z2 cluster together, and

(2) the sites on Transects CC and DD form a single larger grouping.

The stations on Transect EE, nearest Hastings Arm, are loosely grouped with those stations in Hastings Arm (Z2), but it should be noted that both clusters are linked at a rather low level of similarity (0.3).

Descriptive Analysis

A comparison of the number of individual organisms grouped on the basis of the Bray-Curtis analysis of 1982 data (Fig. 5) shows a large increase in the fauna of the Group I cluster (Table 1), which is also matched by an increase in the number of taxa present (Table 2). There is a contrasting reduction in density and reduction in taxa at all but two of the other stations from 1982 to 1983. These opposite trends combine to remove the distinction between stations on Transects CC and DD, although it is of interest to note that each of the three

Fig. 3. Cluster analysis station groupings using Ward's index (from Kathman et al., 1983).

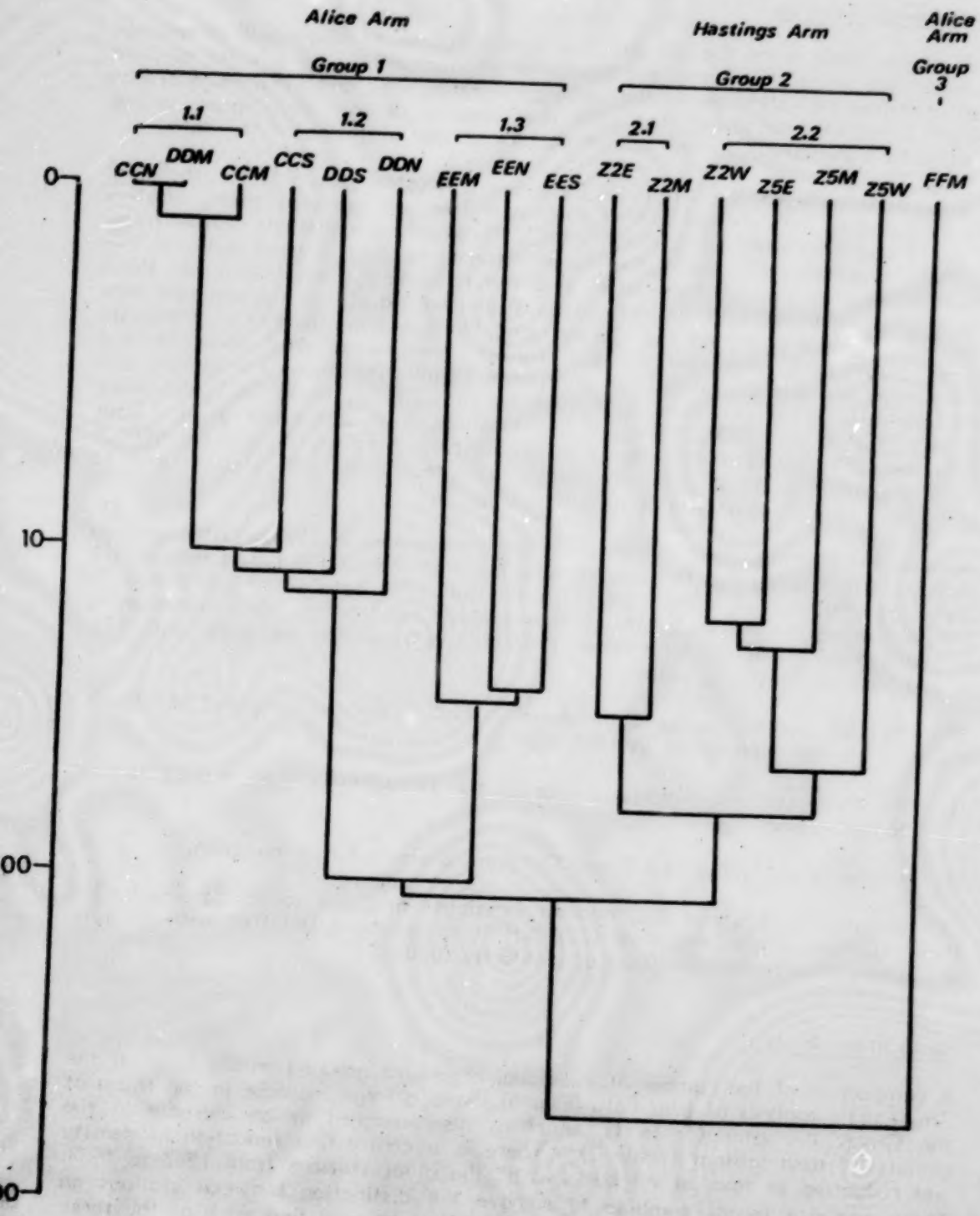


Fig. 4. Cluster analysis station groupings for 1982 original 15-station data matrix using Bray-Curtis index.

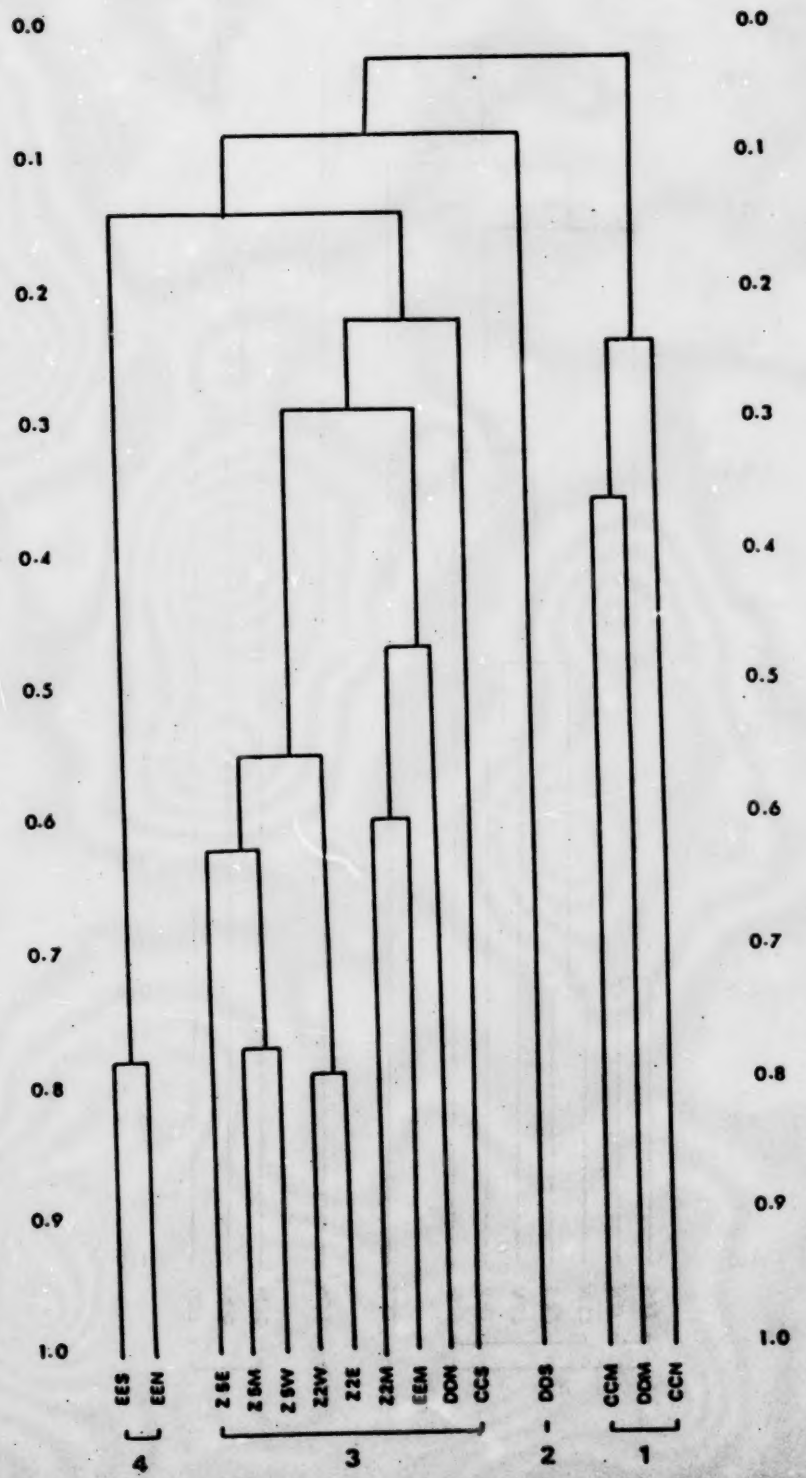


Fig. 5. Cluster analysis station groupings for MI, 1982.

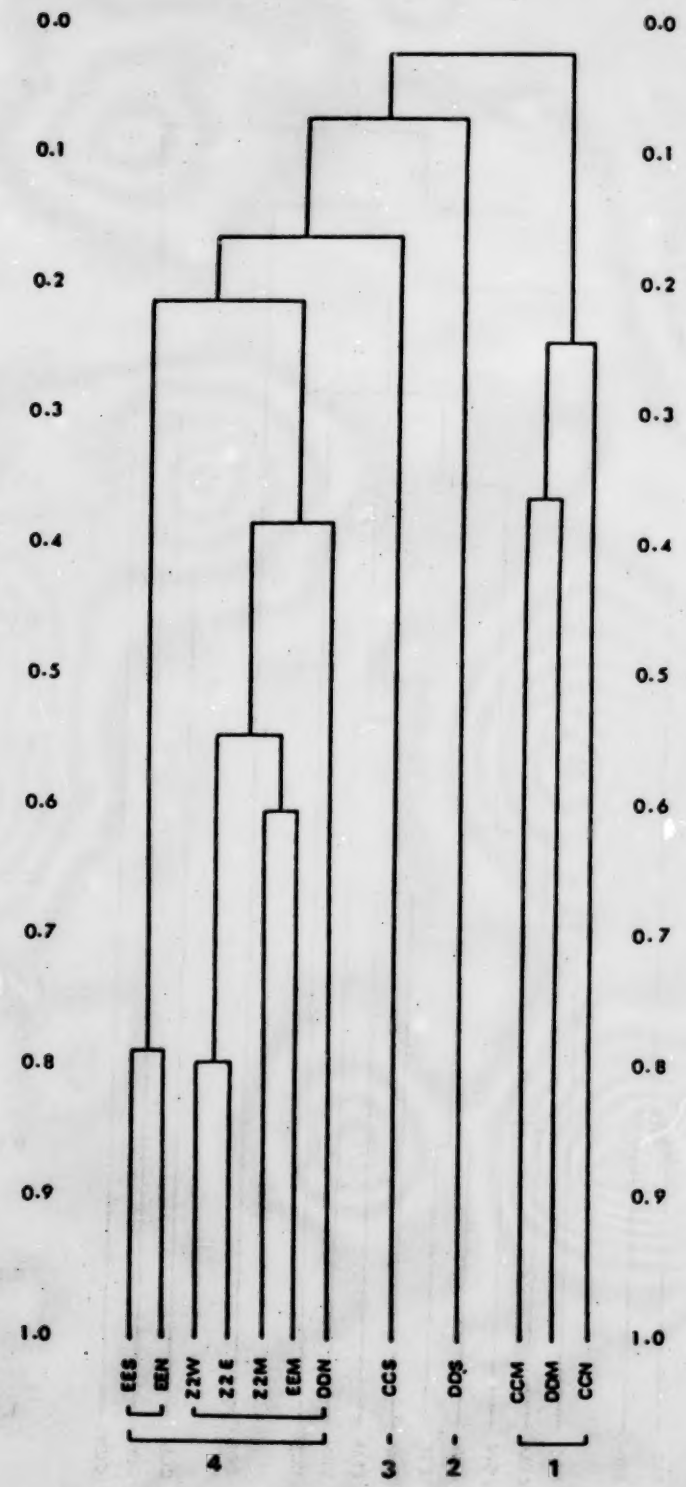


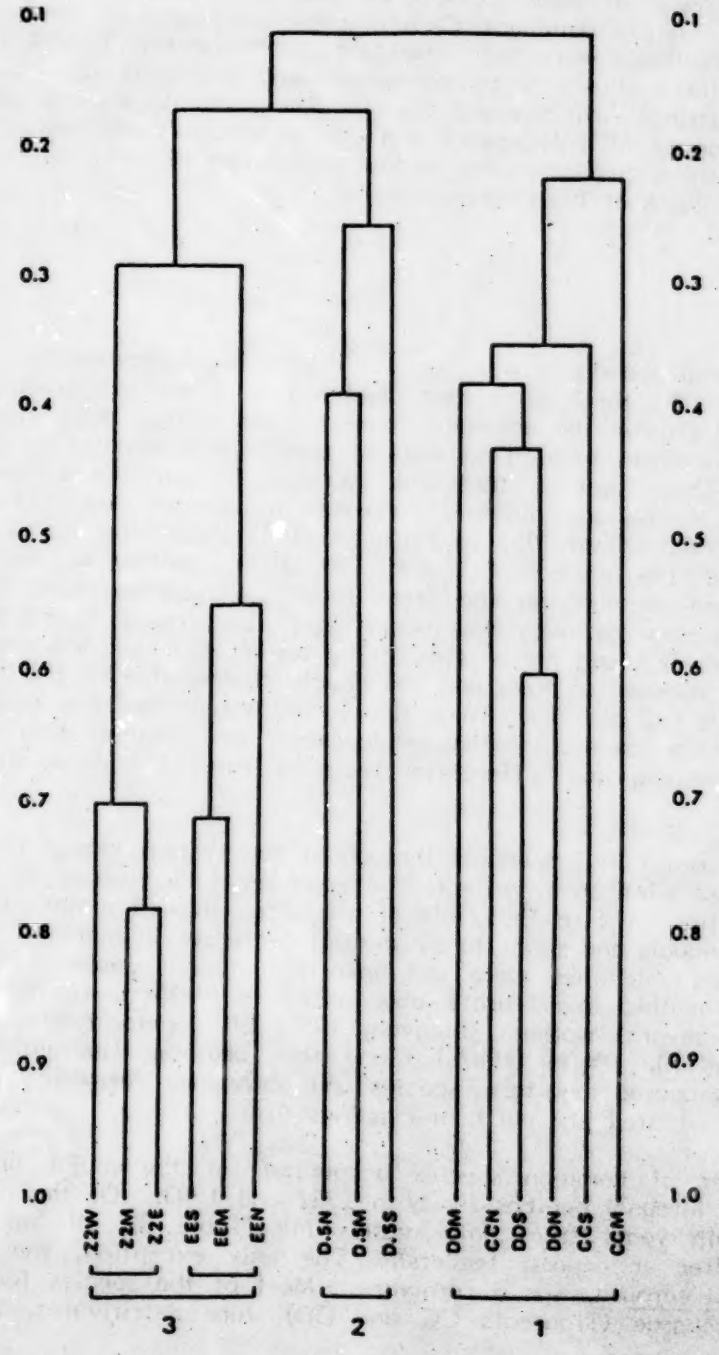
Table 1. Differences in numbers of benthic invertebrates between 1982 and 1983 per cluster grouping (from Fig. 5).

Station	1982		1983		
	Number of Individuals	Number of Individuals/ Cluster Grouping	Number of Individuals	Number of Individuals/ Cluster Grouping	Percent Change in 1983
CCN	20		115		
DDM	25	75	90	275	+367
CCM	30		70		
DDS	1,085	1,085	205	205	- 81
CCS	665	665	220	220	- 67
DDN	520		165		
EEM	1,040		1,190		
Z2M	1,255	6,735	760	3,920	- 42
Z2W	2,085		985		
Z2E	1,835		820		
EEN	3,125		665		
EES	3,440	6,565	1,655	2,485	- 62

Table 2. Differences in numbers of taxa between 1982 and 1983 per cluster grouping (from Fig. 5).

	1982		1983		
Station	Number of Taxa	Number of Taxa/Cluster Grouping	Number of Taxa	Number of Taxa/Cluster Grouping	Percent Change in 1983
CCN	4		15		
DDM	4	9	9	23	+256
CCM	5		7		
DDS	10	10	20	20	+200
CCS	24	24	17	17	- 29
DDN	20		14		
EEM	21		20		
Z2M	30	57	31	50	- 12
Z2W	37		27		
Z2E	38		32		
EEN	37		10		
EES	38	51	23	26	- 49

Fig. 6. Cluster analysis station groupings for MI, 1983.



stations of Group I (1982) still had the lowest numbers of individuals (115, 90, 70) when compared with the rest of the CC and DD stations (205, 220, 165). Shared species differences presumably prevented recognition of the 1982 Group I stations in 1983.

Polychaetes, molluscs (bivalves) and crustaceans were equally abundant (33%, 31% and 31%, respectively) at Sites CCN, CCM and DDM (App. E and F), while polychaetes were clearly dominant (54%) at the remaining CC and DD sites. Polychaetes and molluscs were both abundant at Transect D.5 (44% and 37%, respectively), while molluscs were overwhelmingly abundant at Transect EE (83%) and the Hastings Arm transect (81%). These results show a progression from high abundances of polychaetes and low abundances of molluscs at the sites nearest the mine discharge area to low abundances of polychaetes and high abundances of molluscs at the reference sites.

DISCUSSION

Changes in infaunal abundance were readily distinguished between the 1982 and 1983 data sets. The three sites that clustered as a distinct grouping (CCN, CCM, DDM) and showed the strongest impact from tailings deposition in 1982 had substantial increases in both numbers of species and numbers of individuals during 1983. There was a threefold increase in polychaete species and individuals, and three- and ninefold increases in species and individuals of molluscs, respectively, from 1982 to 1983. In 1983 these sites could no longer be differentiated from other CC and DD sites, indicating that benthic invertebrates were recolonizing the areas most adversely affected by tailings deposition and a slow recovery was occurring. However, the two deep sites (CCM, DDM) midway along the bottom of the trough in Alice Arm continued to have the lowest number of taxa and individuals compared with the other four sites on Transects CC and DD. These deeper areas remained the most severely affected possibly due to more extensive deposition and accumulation of tailings coupled with slumping and differential recovery rates for deepwater benthic organisms.

The uniform decrease in individuals throughout the system except at the 1982 discharge-affected sites again reflects the recovery taking place in that area. With the exception of Site DDS, all of the sites showed major reduction in numbers of individuals and slight to substantial decreases in numbers of species. Reasons for these declines were not investigated, but seasonal and annual fluctuations in benthic invertebrate abundances in northern fjords have been documented by several workers (Blegvad, 1950; Ellis, pers. comm. and 1960; VTN, 1982a and b). VTN (1982b) found that seasonal fluctuations of the subtidal benthos caused long-term species and abundance variability in Boca de Quadra, a fjord situated just north of Hastings Arm.

A small number of common species accounted for the major distributional patterns of the infaunal benthos for both 1982 and 1983. Of the nine species common to both years from data matrix M4 (Table 3), all but one were detritivores (filter or deposit feeders). The only exception, the polychaete Nephtys cornuta cornuta, was a carnivore. Most of the species found nearest the former discharge (Transects CC and DD) were detritivores, but as the

distance from the discharge increased the number of feeding groups also increased, indicating a greater diversity within the benthic community down inlet and in adjacent Hastings Arm.

Table 3. List of abundant species common to 1982 and 1983 samplings, from data matrix M4.

Polychaeta:	*Myriochele oculata*
	Nephtys cornuta cornuta
	Levinsenia gracilis
Cumacea:	*Eudorella pacifica*
Mollusca:	*Cylichna alba*
	Cooperella subdiaphana
	Nucula tenuis
	Psephidia lordi
	Yoldia martyria

An increased, but equal, abundance of polychaetes, molluscs and crustaceans was found at Sites CCN, CCM and DDM, the most adversely affected sites in 1982, 11 months after mine tailings discharge had ceased. In a three year study of benthic colonization in natural substrates, Arntz and Rumohr (1982) found approximately equal proportions of polychaetes (45%) and molluscs (55%) after 11 months of colonization. Polychaetes were initially dominant but molluscs increased after the first six months and remained dominant during the following two years of the study. It is too early to determine if succession in Alice Arm will follow a similar pattern.

Recovery of the infaunal benthos was noticeable 11 months after discharge terminated even at the most affected sites in Alice Arm (Sites CCN, DDM and CCM). Diversity of all species groups increased at these sites, together with significant increases in abundances. This pattern agreed with the study by Arntz and Rumohr (1982), who found that species numbers initially increased very slowly, abundance changed from low at the pre-opportunistic stage to high during the opportunistic period, and numerical dominance changed very rapidly during the early stages. Although polychaetes were slightly dominant at these sites in Alice Arm, the largest percentage increases were recorded for bivalves and crustaceans. The cumacean Eudorella pacifica and the bivalves Nucula tenuis and Macoma carlottensis were common early colonizing species. Similar results have been reported by other investigators. In a study of benthic repopulation in the Raritan River estuary following sewage abatement, Dean and Haskin (1964) found Macoma sp. to be a pioneer among the species of early invaders. Arntz and Rumohr (1982) found that cumaceans often predominated during the summer. However, it is important to note that although many studies have dealt with marine benthic invertebrate colonization (e.g. Arntz and Rumohr, 1982; Bonsdorff, 1980; Dean and Haskin, 1964; Kathman et al., 1984; Pearson and Rosenberg, 1978), no previous studies have dealt specifically with recolonization following cessation of mine tailings discharge. As such this study is unique, and it provides valuable data related to predicting the ultimate recovery of other coastal areas presently (or proposed to be) impacted by mine tailings discharges.

RECOMMENDATIONS

The study of spatial and temporal marine infaunal benthic colonization at Alice and Hastings Arms provides a unique opportunity to monitor long-term biological effects after mine tailings disposal has ceased. We therefore recommend that greater than minimum effort be expended in benthic monitoring. Specifically, we strongly recommend initiation of a quarterly sampling program, to start immediately and to continue for the next several years. The data from such an intensified program would be fundamental to the development of rates of recolonization/die off, within season fluctuations, biological aspects of slower recolonization in deep areas, and possible limiting factors of recolonization in tailings affected sediments.

At a minimum, an annual benthic sampling program to monitor changes in the distribution and abundance of benthic invertebrates in Alice Arm should be continued at a level consistent with the 1982 and 1983 studies while the mine is closed. If mill operations resume, however, the benthos should be sampled immediately prior to operations, followed by biannual sampling for the first year after startup and annual sampling afterwards. This program would serve to determine immediate and long-term effects of tailings discharges on the infaunal benthic community.

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APPENDIX A

INFORMATION RECORDED DURING SAMPLE ACQUISITION

Date (October, 1983)	Station*	Avg. Depth (m)	North Latitude West Longitude
05	CCN	261.5	55°26'40" 129°31'42"
05	CCM	271.0	55°26'36" 129°31'53"
05	CCS	249.5	55°26'3" 129°31'44"
05	DDN	340.0	55°26'48" 129°33'37"
05	DDM	347.0	55°26'44" 129°33'35"
05	DDS	350.0	55°26'41" 129°33'31"
06	D.5N	327.0	55°27'10" 129°35'27"
06	D.5M	387.0	55°27'05" 129°35'23"
06	D.5S	376.0	55°27'02" 129°35'23"
06	EEN	375.5	55°27'12" 129°37'00"
06	EEM	394.0	55°27'06" 129°37'00"
06	EES	394.0	55°27'00" 129°37'00"
06	Z2E	296.0	55°29'19" 129°45'37"
06	Z2M	298.0	55°29'17" 129°45'50"
06	Z2W	298.0	55°29'14" 129°45'57"

*Stations CCN through EES are in Alice Arm; Z2E through Z2W are in Hastings Arm.

APPENDIX B

RESULTS OF QUALITY CONTROL (QC) FOR SORTING BENTHIC INVERTEBRATES

Sample Identification	Total Number of Individuals During Sorting	Total Number of Individuals After QC	Percent Error for Sample
DDS-B	21	21	0
D.5M-A	40	40	0
EEM-B	121	123	1.6
EES-A	122	123	0.8
EES-B	209	210	0.5
Z2E-A	80	81	1.2
Z2W-A	85	86	1.2

APPENDIX C

LIST OF TAXONOMIC REFERENCES

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APPENDIX D

LIST OF ALL TAXA FOUND IN ALICE ARM AND HASTINGS ARM

Coelenterata
- Anthozoa
  - Actiniaria
    - Edwardsiidae
      - *Edwardsia sipunculoides* (Stimpson)
  - Pennatulacea
    - Virgulariidae
      - *Virgularia* sp. aff. *tuberculata* Marshal

Nemertea
- Anopla
  - Heteronemertea
    - Cerebratulidae
      - *Cerebratulus* sp.

Bryozoa

Annelida
- Polychaeta
  - Capitellida
    - Capitellidae
      - *Heteromastus filobranchus* Berkeley and Berkeley
    - Maldanidae
      - *Maldane glebifex* Grube
  - Eunicida
    - Lumbrineridae
      - *Lumbrineris luti* Berkeley and Berkeley
      - *Paraninoe simpla* (Moore)
  - Flabelligerida
    - Flabelligeridae
      - *Brada villosa* (Rathke)
  - Orbiniida
    - Orbiniidae
      - *Leitoscoloplos pugettensis* (Pettibone)

APPENDIX D (cont.)

Paraonidae
Levinsenia gracilis (Tauber)
Aricidea (Allia) suecica Eliason

Oweniida
Oweniidae
Myriochele oculata Zachs

Phyllodocida
Goniadidae
Goniada annulata Moore

Hesionidae
Gyptis brevipalpa (Hartmann-Schroder)

Nephtyidae
Nephtys cornuta cornuta Berkeley and Berkeley
Nephtys punctata Hartman
Aglaophamus malmgreni (Theel)

Pilargidae
Ancistrosyllis groenlandica McIntosh

Polynoidae
Harmothoinae
?Antinoella sarsi (Kinberg)

Sigalionidae
Pholoe minuta (Fabricius)

Spionida
Cirratulidae
Chaetozone setosa Malmgren
Tharyx multifilis Moore

Spionidae
Polydora sp.
Prionospio steenstrupi Malmgren
Spiophanes sp.
Spiophanes kroyeri Grube

Sternaspida
Sternaspidae
Sternaspis scutata (Renier)

Terebellida
Ampharetidae
Amphicteis sp.
Ampharete finmarchica (Sars)

APPENDIX D (cont.)

Pectinariidae
Amphictene moorei Annenkova

Trichobranchidae
Terebellides stroemi Sars

Arthropoda
Crustacea
Amphipoda
Lysianassidae
Koroga megalops Holmes
Pachynus barnardi Hurley

Oedicerotidae
Bathymedon pumilis Barnard
Monoculodes cf. *emarginatus* Barnard
Monoculodes sp. ?

Cumacea
Diastylidae
Diastylis pellucida Hart

Leuconidae
Eudorella pacifica Hart
Leucon subnasica Hart

Mysidacea
Mysidae
Holmesiella anomala Ortmann

Ostracoda

Mollusca
Caudofoveata
Chaetodermatida
Crystallophrissonidae
Crystallophrisson sp.[1]

Gastropoda
Cephalaspidea
Cylichnidae
Cylichna alba (Brown)
Cylichna attonsa Carpenter

Mesogastropoda
Rissoinidae
Rissoina newcombei Dall

APPENDIX D (cont.)

Neogastropoda
Muricidae
Ocenebra interfossa Carpenter

Scaphopoda
Dentaliida
Dentaliidae
Dentalium agassizii Pilsbry and Sharp
Dentalium pretiosum Sowerby

Leavidentalidae
Rhabdus rectius (Carpenter)

Gadilida
Cadulidae
Cadulus tolmiei Dall

Bivalvia
Myoida
Myidae
Mya arenaria Linnaeus

Nuculoidea
Nuculanidae
Nuculana hindsii (Hanley)

Nuculidae
Nucula tenuis (Montagu)

Yoldiidae
Yoldia hyperborea Torell
Yoldia martyria Dall
Yoldia scissurata Dall
Yoldia thraciaeformis (Storer)

Veneroida
Cardiidae
Clinocardium nuttallii (Conrad)

Cooperellidae
Cooperella subdiaphana (Carpenter)

Lucinidae
Lucina tenuisculpta Carpenter

Tellinidae
Macoma calcarea (Gmelin)
Macoma carlottensis Whiteaves
Macoma eliminata Dunnill and Coan

Veneridae
Psephidia lordi (Baird)[2]

Echinodermata
  Asteroidea
    Paxillosida
      Goniopectinidae
        Ctenodiscus crispatus (Retzius)

  Echinoidea
    Echinoida
      Strongylocentrotidae
        Strongylocentrotus prob. *pallidus* (G.O. Sars)

  Holothuroidea
    Apodida
      Chiridotidae
        Chiridota albatrossi Ohshima[3]

    Molpadida
      Molpadiidae
        Molpadia intermedia (Ludwig)

  Ophiuroidea
    Ophiurida
      Ophiuridae
        Ophiura leptoctenia H.L. Clark

[1]of Filatova; = *Chaetoderma* of Salvini-Plawen

[2]all *Transenella tantilla* of Kathman et al., 1983 = *P. lordi*

[3]of Ohshima; = *C. laevis* of Deichmann

APPENDIX E

DENSITY AND DISTRIBUTION FOR BENTHIC INVERTEBRATES FROM ALICE ARM

All Results are Given in Numbers Per m^2

	CCN			CCH			CCS			DDN			DDM			DDS		
	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Coelenterata																		
Anthozoa																		
Actiniaria																		
Edwardsiidae																		
Edwardsia sipunculoides										10	5							
Pennatulacea																		
Virgulariidae																		
Virgularia sp. aff. *tuberculata*																		
Nemertea																		
Anopla																		
Heteronemertea																		
Cerebratulidae																		
Cerebratulus sp.																		
Bryozoa	10		5															
Annelida																		
Polychaeta																		
Capitellida																		
Capitellidae																		
Heteromastus filobranchus										10	5							
Maldanidae																		
Maldane glebifex								50	25									
Eunicida																		
Lumbrineridae																		
Lumbrineris luti				10	10	10		10	5								10	5
Ypsaninae simplo		20	10															
Flabelligerida																		
Flabelligeridae																		
Brada villosa																		
Orbiniida																		
Orbiniidae																		
Leitoscoloplos pugettensis	10		5															
Paraonidae																		
Levinsenia gracilis							40	40	40				20		10		10	5
Aricidea (Allia) suecica																		
Ouenida																		
Ouenidae																		
Myriochele oculata	10	10	10				10	80	45	60	20	40		10	5		10	5
Phyllodocida																		
Goniadidae																		
Goniada annulata								10	5	10		5	20		10	10		5
Hesionidae																		
Gyptis brevipalpa																		
Nephtyidae																		
Nephtys cornuta cornuta							10		5	40		20				60	10	35
Nephtys punctata																	10	5
Aglaophamus malmgreni																		
Pilargidae																		
Ancistrosyllis groenlandica																		
Polynoidae																		
Harmothoinae																	10	5
?Antinoella sarsi	10		5															
Sigalionidae																		
Pholoe minuta																		
Spionida																		
Cirratulidae																		
Chaetozone setosa													20		10	10		5
Tharyx multifilis								30	15									
Spionidae																		
Polydora sp.	10		5															
Prionospio steenstrupi																10	10	10
Spiophanes sp.				10		5												
Spiophanes bombyx																		

	D.SW			D.SW			D.SS			EEN			EEN			EES		
	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Coelenterata																		
Anthozoa																		
Actiniaria																		
Edwardsiidae																		
Edwardsia sipunculoides																		
Pennatulacea																		
Virgulariidae																		
Virgularia sp. aff. tuberculata																		
Nemertea																		
Anopla																		
Heteronemertea																		
Cerebratulidae																		
Cerebratulus sp.							10		5									
Bryozoa																		
Annelida																		
Polychaeta																		
Capitellida																		
Capitellidae																		
Heteromastus filobranchus													10		5	10		5
Maldanidae																		
Maldane glebifex																		
Eunicida																		
Lumbrineridae																		
Lumbrineris luti																10		5
Paraninoe simpla	10		5														10	5
Flabelligerida																		
Flabelligeridae																		
Brada villosa																		
Orbiniida																		
Orbiniidae																		
Leitoscoloplos pugettensis							40	30	35							10		5
Paraonidae																		
Levinsenia gracilis				10		5				10		5	10	30	20	10		5
Aricidea (Allia) suecica		10	5		10	5								10	5			
Ovenida																		
Ovenidae																		
Myriochele oculata		10	5				10	20	15							20		10
Phyllodocida																		
Goniadidae																		
Goniada annulata	10		5											20	10	10	10	10
Nesionidae																		
Gyptis brevipalpa					10	5	10		5					20	10			
Nephtyidae																		
Nephtys cornuta cornuta		40	20	50	10	30	40	70	55	40	20	30	10		5	10	20	15
Nephtys punctata		10	5	10	30	20	20		10				20	10	15		10	5
Aglaophamus malmgreni		10	5				10		5									
Pilargidae																		
Ancistrosyllis groenlandica		10	5															
Polynoidae																		
Harmothoinae																		
?Antinoella sarsi																		
Sigalionidae																		
Pholoe minuta		10	5				10		5				10		5			
Spionida																		
Cirratulidae																		
Chaetozone setosa							20		10							10		5
Tharyx multifilis																		
Spionidae																		
Polydora sp.																		
Prionospio steenstrupi		30	15		10	5								10	5			
Spiophanes sp.																		
Spiophanes kroyeri																		

	CCW			CCM			CCS			DDW			DDM			DDS		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Sternaspida																		
Sternaspidae																		
Sternaspis scutata																		
Terebellida																		
Ampharetidae																		
Amphicteis sp.							10		5									
Ampharete finmarchica																		
Pectinariidae																		
Amphictene moorei		10	5								10	5				20	10	15
Trichobranchidae																		
Terebellides stroemi								10	5									
Arthropoda																		
Crustacea																		
Amphipoda																		
Lysianassidae																		
Koroga megalops					10	5												
Pachynus barnardi																		
Oedicerotidae																		
Bathymedon pumilis							10		5	10		5						
Monoculodes cf. *emarginatus*	10		5				10		5	10		5				10		5
Monoculodes sp. Y		10	5															
Cumacea																		
Diastylidae																		
Diastylis pellucida													10		5		10	5
Leuconidae																		
Eudorella pacifica	30	20	25	10	10	10	30	30	30	20	20	20	50	20	35	40	20	25
Leucon subnasica																		
Mysidacea																		
Mysidae																		
Holmesiella anomala																		
Ostracoda																		
Mollusca																		
Caudofoveata																		
Chaetodermatida																		
Crystallophrissonidae																		
Crystallophrisson sp.								10	5									
Gastropoda																		
Cephalaspidea																		
Cylichnidae																		
Cylichna alba							10		5							20		10
Cylichna attonsa								10	5									
Mesogastropoda																		
Rissoinidae																		
Rissoina newcombei																		
Neogastropoda																		
Muricidae																		
Ocenebra interfossa																		
Scaphopoda																		
Dentalida																		
Dentaliidae																		
Dentalium agassizii																		
Dentalium pretiosum																		
Leavidentaliidae																		
Rhabdus rectius																		
Gadilida																		
Cadulidae																		
Cadulus tolmiei																		
Bivalvia																		
Myoida																		
Myidae																		
Mya arenaria				30		15		20	10		20	10	10		5	10	10	10
Nuculoidea																		
Nuculanidae																		
Nuculana hindsii																		

	D.SH			D.SH			D.SS			EEN			EEN			EES		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Sternaspida																		
Sternaspidae																		
Sternaspis scutata	100	190	145													20		10
Terebellida																		
Ampharetidae																		
Amphicteis sp.																		
Ampharete finmarchica																		
Pectinariidae																		
Amphictene moorei																		
Trichobranchidae																		
Terebellides stroemi																		
Arthropoda																		
Crustacea																		
Amphipoda																		
Lysianassidae																		
Koroga megalops																		
Pachynus barnardi																		
Oedicerotidae																		
Bathymedon pumilis		10	5													10		5
Monoculodes cf. emarginatus				10		5				10		5						
Monoculodes sp. 7																		
Cumacea																		
Diastylidae																		
Diastylis pellucida																		
Leuconidae																		
Eudorella pacifica										10	80	45	30	10	20	30	20	25
Leucon subnasica					10	5												
Mysidacea																		
Mysidae																		
Holmesiella anomala																	10	5
Ostracoda																		
Mollusca																		
Caudofoveata																		
Chaetodermatida																		
Crystallophrissonidae																		
Crystallophrisson sp.	10	20	15		10	5	10		5				10		5			
Gastropoda																		
Cephalaspidea																		
Cylichnidae																		
Cylichna alba				30		15												
Cylichna attonsa	10	20	15				10		5								10	5
Mesogastropoda																		
Rissoinidae																		
Rissoina newcombei																		
Neogastropoda																		
Muricidae																		
Ocenebra interfossa																		
Scaphopoda																		
Dentaliida																		
Dentaliidae																		
Dentalium agassizii																		
Dentalium pretiosum													20		10			
Leavidentaliidae																		
Rhabdus rectius														10	5			
Gadilida																		
Cadulidae																		
Cadulus tolmiei																		
Bivalvia																		
Myoida																		
Myidae																		
Mya arenaria											10	5	10	20	15			
Nuculoidea																		
Nuculanidae																		
Nuculana hindsii																	20	10

	CCN			CCM			CCS			DDN			DDM			DDS		
	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$	A	B	$\bar{x}$
Nuculidae																		
Nucula tenuis		10	5	20	20	20					40	20	10		5		30	15
Yoldiidae																		
Yoldia hyperborea																		
Yoldia martyria																		
Yoldia scissurata																		
Yoldia thraciaeformis											20	10						
Veneroida																		
Cardiidae																		
Clinocardium nuttallii	10		5															
Cooperellidae																		
Cooperella subdiaphana																		
Lucinidae																		
Lucina tenuisculpta										10		5				10		5
Tellinidae																		
Macoma calcarea																		
Macoma carlottensis	10	20	15		10	5					10	5					30	15
Macoma elimata																		
Veneridae																		
Psephidia lordi		10	5											10	5			
Echinodermata																		
Asteroidea																		
Paxillosida																		
Goniopectinidae																		
Ctenodiscus crispatus																		
Echinoidea																		
Echinoida																		
Strongylocentrotidae																		
Strongylocentrotus prob. *pallidus*																		
Holothuroidea																		
Apodida																		
Chiridotidae																		
Chiridota albatrossi		10	5														10	5
Molpadida																		
Molpadiidae																		
Molpadia intermedia	10		5				10		5	30		15					30	15
Ophiuroidea																		
Ophiurida																		
Ophiuridae																		
Ophiura leptoctenia																		

	D.3W			D.9W			D.9S			EEN			EEW			EES		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Nuculidae																		
Nucula tenuis	30	20	25	20	40	30				80	60	70	180	150	165	140	300	220
Yoldiidae																		
Yoldia hyperborea																		
Yoldia martyria																		
Yoldia scissurata							10		5									
Yoldia thraciaeformis		10	5															
Veneroida																		
Cardiidae																		
Clinocardium nuttallii																		
Cooperellidae																		
Cooperella subdiaphana																		
Lucinidae																		
Lucina tenuisculpta	30	50	40	60	70	65				10	10	10	20	70	45		50	25
Tellinidae																		
Macoma calcarea																		
Macoma carlottensis					10	5							10	30	20	10		5
Macoma elimata																10		5
Veneridae																		
Psephidia lordi		40	20	160	30	95	30		15	420	350	385	700	700	700	860	1580	1220
Echinodermata																		
Asteroidea																		
Paxillosida																		
Goniopectinidae																		
Ctenodiscus crispatus		20	10		10	5												
Echinoidea																		
Echinoida																		
Strongylocentrotidae																		
Strongylocentrotus prob. pallidus					10	5												
Holothuroidea																		
Apodida																		
Chiridotidae																		
Chiridota albatrossi	10	60	35	40	90	65	60	10	35	90	110	100	120	110	115	30	50	40
Molpadida																		
Molpadiidae																		
Molpadia intermedia	10		5				20		10	10	10	10	10	10	10			
Ophiuroidea																		
Ophiurida																		
Ophiuridae																		
Ophiura leptoctenia																20		10

APPENDIX F

DENSITY AND DISTRIBUTION FOR BENTHIC INVERTEBRATES FROM HASTINGS ARM
All Results are Given in Numbers Per m^2

	Z2E			Z2M			Z2W		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Coelenterata									
Anthozoa									
Actiniaria									
Edwardsiidae									
Edwardsia sipunculoides									
Pennatulacea	10		5						
Virgulariidae				20		10	10		5
Virgularia sp. aff. *tuberculata*									
Nemertea									
Anopla									
Heteronemertea									
Cerebratulidae									
Cerebratulus sp.									
Bryozoa									
Annelida									
Polychaeta									
Capitellida									
Capitellidae									
Heteromastus filobranchus		20	10	10		5	20	20	20
Maldanidae									
Maldane glebifex									
Eunicida									
Lumbrineridae									
Lumbrineris luti									
Paraninoe simplo		10	5		10	5		20	10
Flabelligerida									
Flabelligeridae									
Brada villosa	10		5						
Orbiniida									
Orbiniidae									
Leitoscoloplos pugettensis									
Paraonidae									
Levinsenia gracilis		40	20	10	20	15	10	40	25
Aricidea (Allia) suecica									
Oweniida									
Oweniidae									
Myriochele oculata									
Phyllodocida									
Goniadidae									
Goniada annulata				30	10	20	10	10	10

APPENDIX F (cont.)

	Z2E			Z2M			Z2W		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Hesionidae									
Gyptis brevipalpa	10		5					10	5
Nephtyidae									
Nephtys cornuta cornuta				20		10		20	10
Nephtys punctata				10		5			
Aglaophamus malmgreni	20		10		10	5		10	5
Pilargidae									
Ancistrosyllis groenlandica									
Polynoidae									
Harmothoinae				10		5			
?Antinoella sarsi									
Sigalionidae									
Pholoe minuta				10		5			
Spionida									
Cirratulidae									
Chaetozone setosa		10	5	10	10	10		10	5
Tharyx multifilis					10	5			
Spionidae									
Polydora sp.									
Prionospio steenstrupi									
Spiophanes sp.									
Spiophanes kroyeri	30		15	10		5			
Sternaspida									
Sternaspidae									
Sternaspis scutata	10	20	15	20	20	20		10	5
Terebellida									
Ampharetidae									
Amphicteis sp.									
Ampharete finmarchica	10	5		10	5				
Pectinariidae									
Amphictene moorei									
Trichobranchidae									
Terebellides stroemi									
Arthropoda									
Crustacea									
Amphipoda									
Lysianassidae									
Karoga megalops									
Pachynus barnardi	10		5						
Oedicerotidae									
Bathymedon pumilis	10		5	10		5			
Monoculodes cf. emarginatus									
Monoculodes sp. ?		10	5						
Cumacea									
Diastylidae									
Diastylis pellucida									
Leuconidae									
Eudorella pacifica	50	10	30	20		10	30	10	20
Leucon subnasica									

APPENDIX F (cont.)

	Z2E			Z2M			Z2W		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Mysidacea									
Mysidae									
Holmesiella anomala									
Ostracoda									
Mollusca	10		5						
Caudofoveata									
Chaetodermatida									
Crystallophrissonidae	10		5	10		5		10	5
Crystallophrisson sp.									
Gastropoda									
Cephalaspidea									
Cylichnidae	10		5	10	50	30			
Cylichna alba									
Cylichna attonsa									
Mesogastropoda									
Rissoinidae								10	5
Rissoina newcombei									
Neogastropoda									
Muricidae	10		5						
Ocenebra interfosso									
Scaphopoda									
Dentaliida									
Dentaliidae	10	20	15	10		5	10		5
Dentalium agassizii									
Dentalium pretiosum									
Leavidentalidae								10	5
Rhabdus rectius									
Gadilida									
Cadulidae	20		10						
Cadulus tolmiei									
Bivalvia									
Myoida									
Myidae	30	60	45	30		15	40	10	25
Mya arenaria									
Nuculoidea									
Nuculanidae									
Nuculana hindsii									
Nuculidae	350	470	410	360	410	385	430	630	530
Nucula tenuis									
Yoldiidae	10	10	10						
Yoldia hyperborea	50	10	30	10		5	20	100	60
Yoldia martyria	10	10	10	10		5			
Yoldia scissurata	10		5	40	30	35	80		40
Yoldia thracioeformis									
Veneroida									
Cardiidae									
Clinocardium nuttallii									

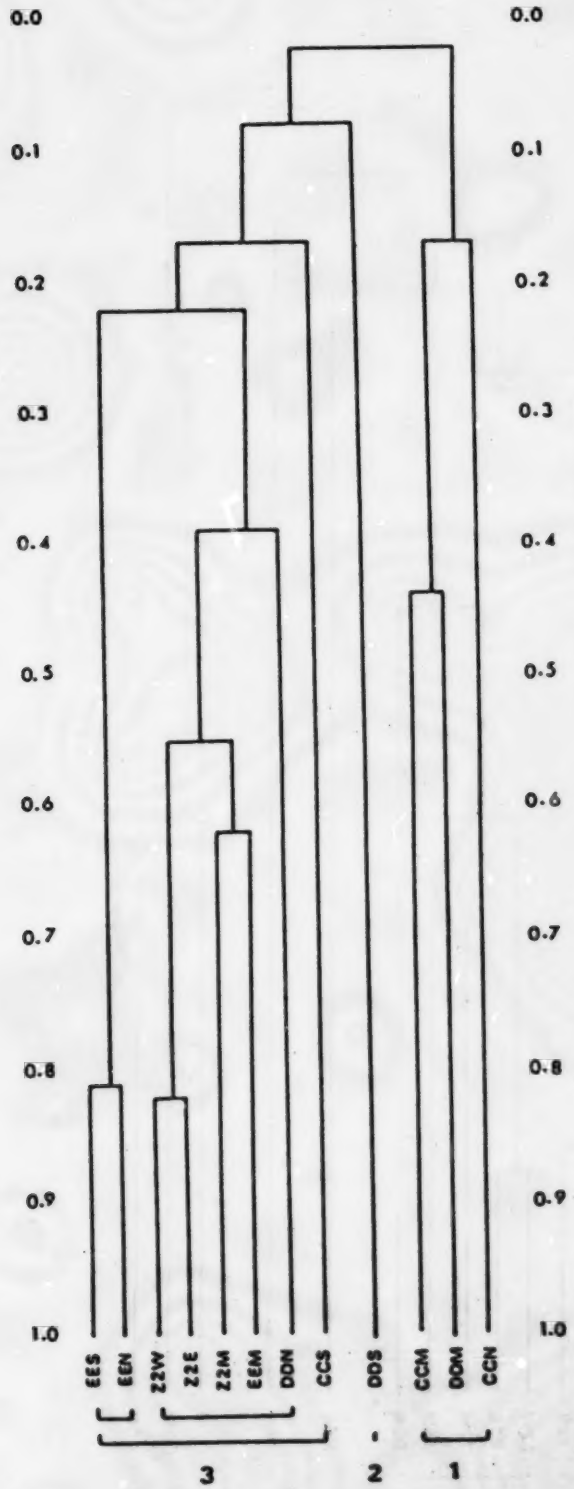
APPENDIX F (cont.)

	Z2E			Z2M			Z2W		
	A	B	$\bar{X}$	A	B	$\bar{X}$	A	B	$\bar{X}$
Cooperellidae									
Cooperella subdiaphana				10		5	30	40	35
Lucinidae									
Lucina tenulsculpta	30	50	40	40	20	30	40	50	45
Tellinidae									
Macoma calcarea							10		5
Macoma carlottensis	10	30	20	30	30	30			
Macoma eliminata							10		5
Veneridae									
Psephidia lordi	30	20	25	10	80	45	90	60	75
Echinodermata									
Asteroidea									
Paxillosida									
Goniopectinidae									
Ctenodiscus crispatus	30		15	20	10	15			
Echinoidea									
Echinoida									
Strongylocentrotidae									
Strongylocentrotus prob. pallidus								20	10
Holothuroidea								10	5
Apodida									
Chiridotidae									
Chiridota albatrossi	20	10	15	10		5		10	5
Molpadida									
Molpadiidae									
Molpadia intermedia		10	5						
Ophiuroidea									
Ophiurida									
Ophiuridae									
Ophiura leptoctenia							10		5

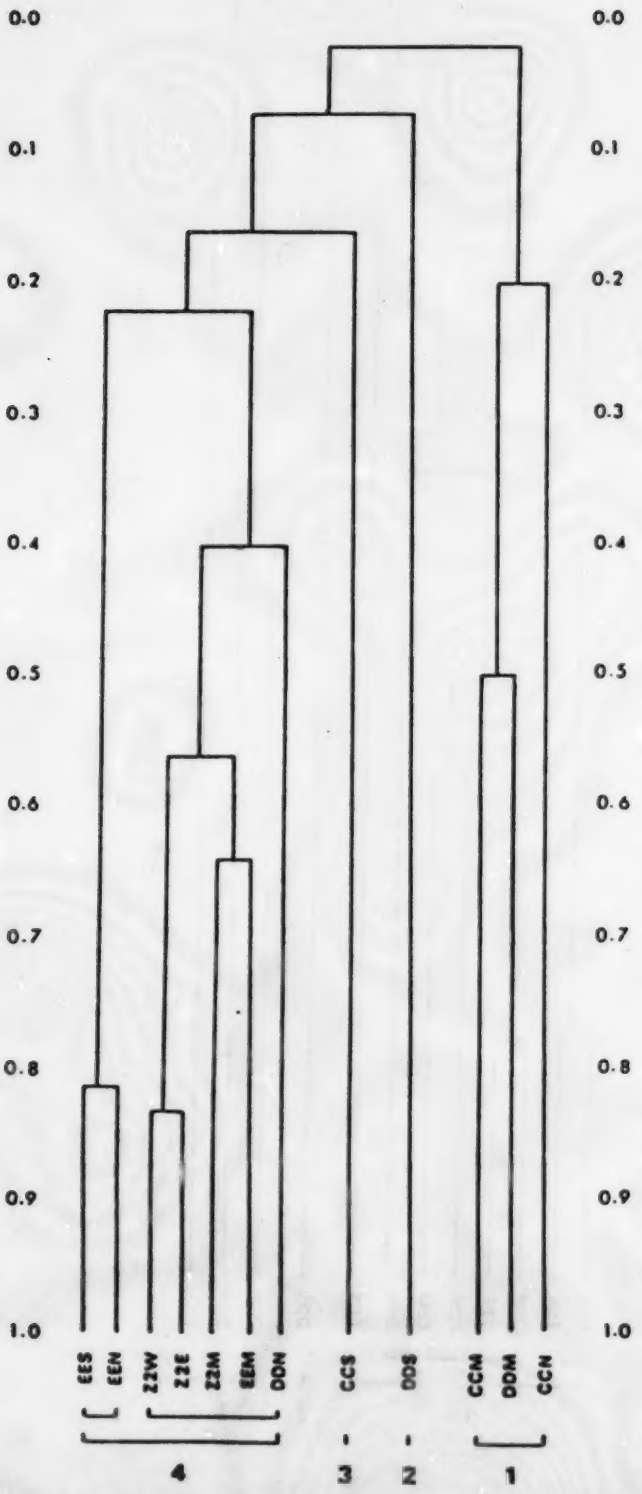
APPENDIX G

CLUSTER ANALYSIS STATION GROUPINGS
M2 - M4; 1982

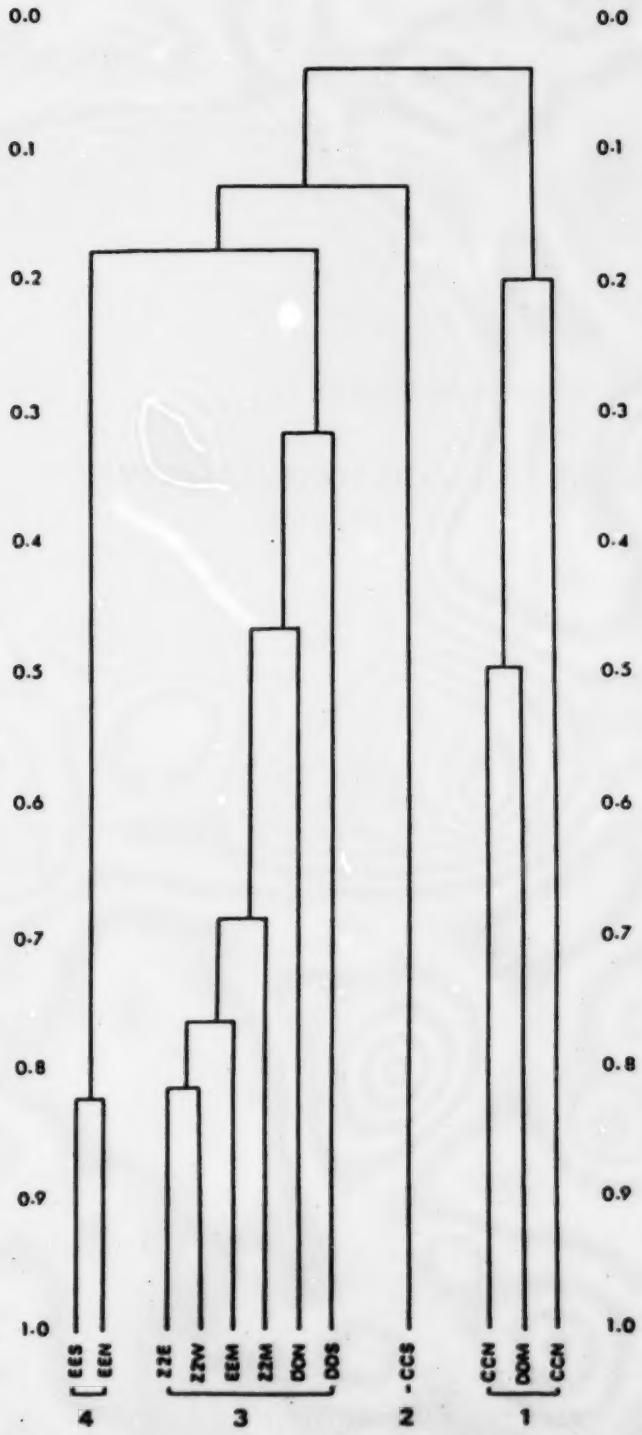
Cluster analysis station groupings for M2, 1982.



Cluster analysis station groupings for M3, 1982.



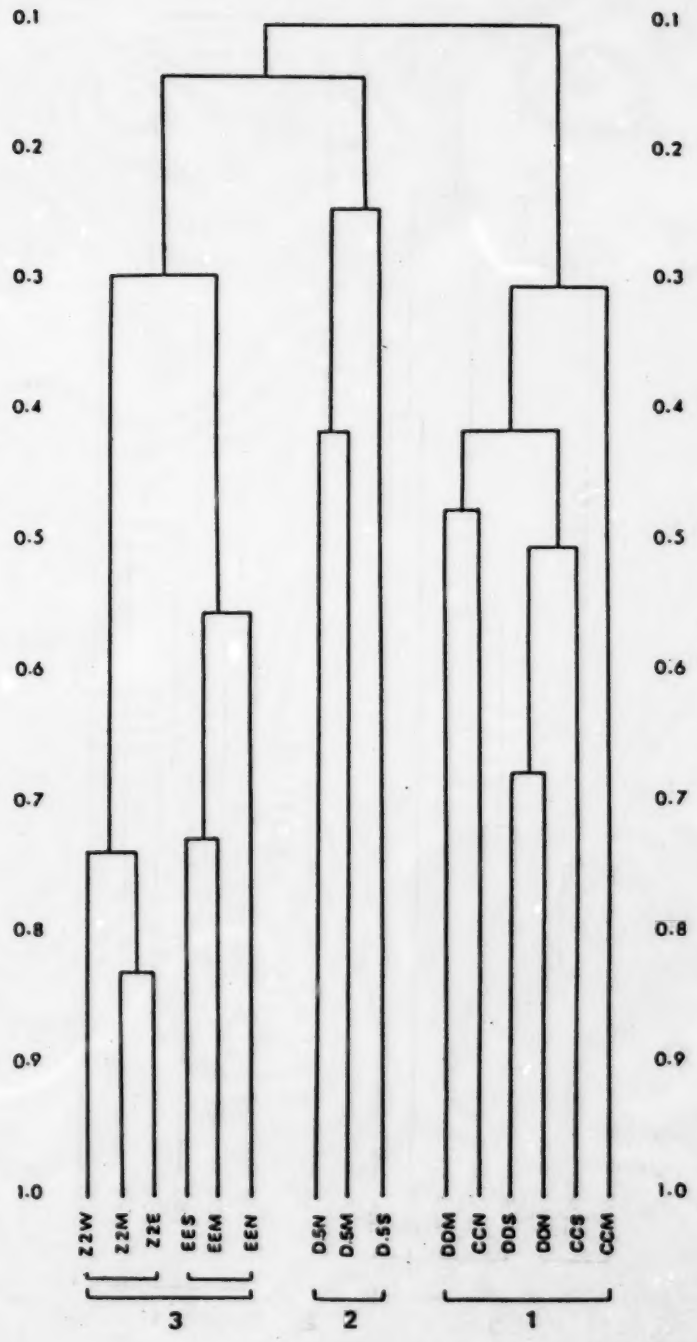
Cluster analysis station groupings for M4, 1982.



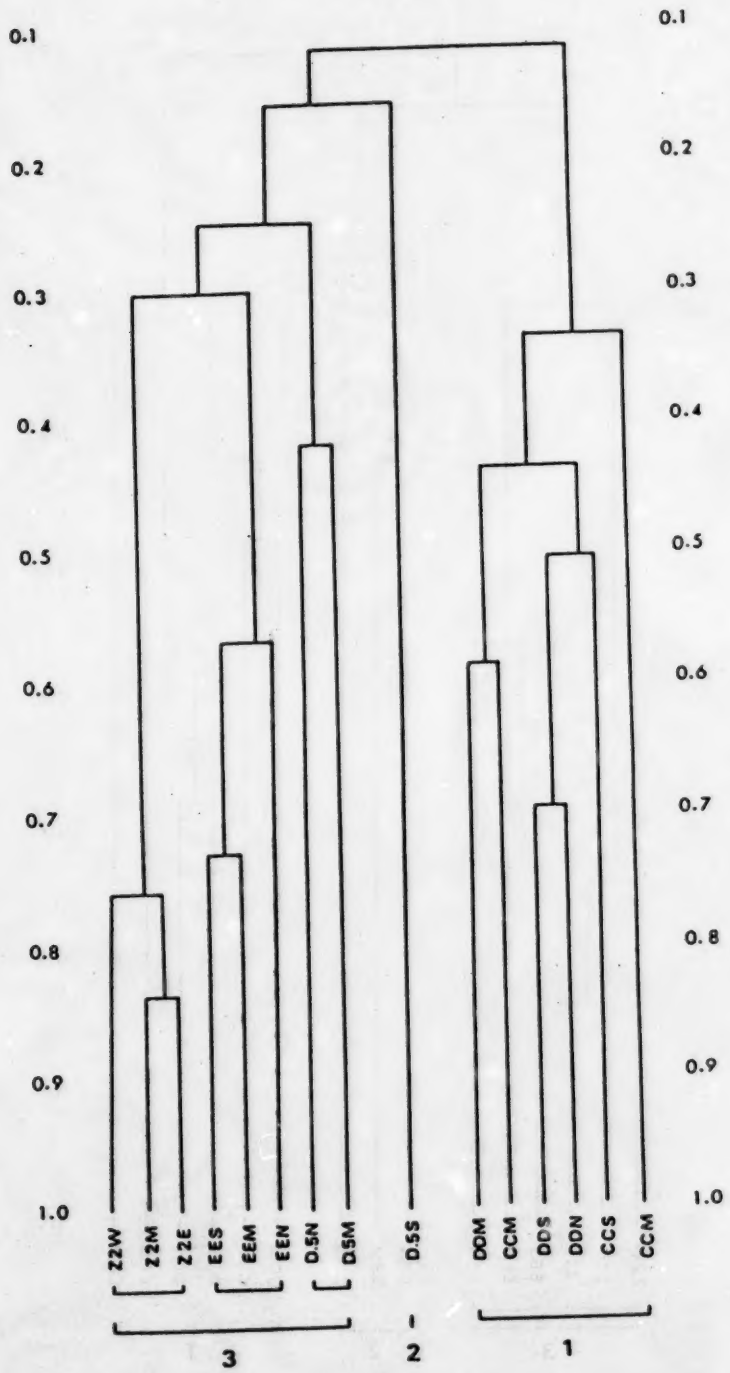
APPENDIX H

CLUSTER ANALYSIS STATION GROUPINGS
M2 - M4; 1983

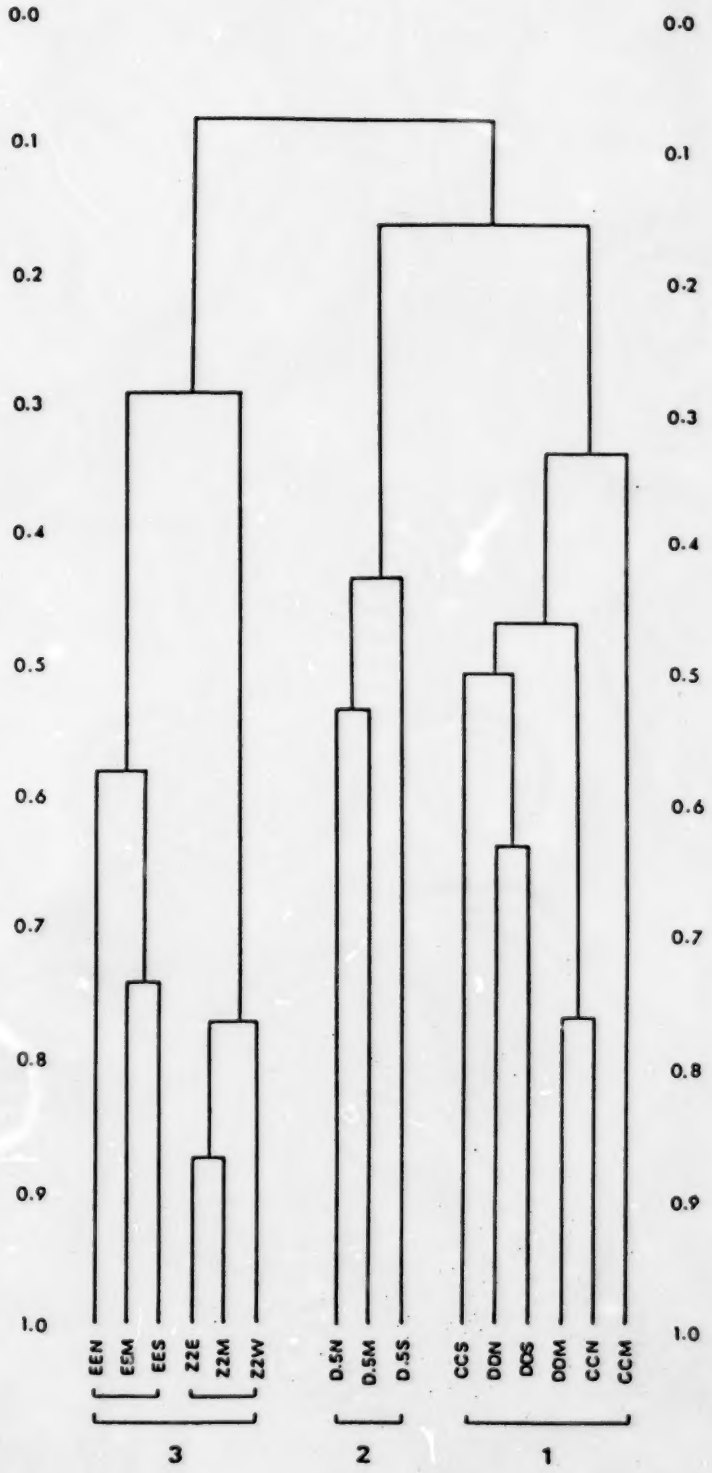
Cluster analysis station groupings for M2, 1983.



Cluster analysis station groupings for M3, 1983.



Cluster analysis station groupings for M4, 1983.



POOR

QUALITY

ORIGINAL